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Electron Momentum Transfer Collision Frequency in N_2, O_2 and Air

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The electron momentum transfer collision frequencies in N_2, O_2 and air are calculated for a Maxwellian electron velocity distribution using several definitions of ν_m. Keywords:

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CONTENTS

ELECTRON MOMENTUM TRANSFER COLLISION FREQUENCY IN N_2, O_2 AND AIR

1. INTRODUCTION

The electron momentum transfer collision frequency plays a significant role in the determination of the conductivity in weakly ionized gases. It can be determined if the momentum transfer cross sections and the electron velocity distributions are known. However, there appears to be several ways of obtaining the electron momentum transfer collision frequency depending on the appropriate applications.

In this report we calculate the electron momentum transfer collision frequency ν_m assuming a Maxwellian electron velocity distribution, using the most current cross sections. We compare these results with each other as well as with other calculations.

2. THE ELECTRON MOMENTUM TRANSFER COLLISION FREQUENCY

The concept of the momentum transfer is most useful in ionized gases under the influence of the electric field, where the velocity distribution is distorted by the action of the field. Under these conditions ν_m is obtained from the following equation[1] where the electron velocity distribution is assumed to be Maxwellian

$$\left\langle\frac{1}{\nu_m}\right\rangle = \frac{8}{3\sqrt{\pi}\,N_o}\left(\frac{m}{2kT}\right)^{5/2}\int_o^\infty \frac{v^3}{\sigma(v)}\,\mathrm{Exp}\left(-\frac{mv^2}{2kT}\right)dv \qquad (1)$$

Here, N_o indicates the density of the atoms or the molecules, $\sigma(v)$ the momentum transfer cross section and the rest of the symbols have their usual

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meaning. The definition given by (1) becomes obvious when one is interested in the electron mobility μ where

$$\mu = \frac{e}{m} \frac{1}{\nu_m} \tag{2}$$

In Eq. (2) one requires the averaging of ν_m to be made where the cross section is in the denominator. Expression (1) is obtained from the general moment equation for any velocity distribution, $f(v)$, where[2]

$$\langle \frac{1}{\nu_m} \rangle = A \int \frac{4\pi v^3}{3\sigma(v)} \frac{\partial f}{\partial v} dv \tag{3}$$

Here A is the normalization constant i.e., $\int f(v)dv=1$. On the other hand, one can also define the momentum transfer collision frequency as

$$\langle \nu_{eff} \rangle = \frac{8}{3\sqrt{\pi}} N_o \left(\frac{m}{2kT}\right)^{5/2} \int_o^\infty v^5 \sigma(v) \, \mathrm{Exp}\left(- \frac{mv^2}{2kT}\right) dv \tag{4}$$

where the velocity distribution is Maxwellian. Obviously the same definition of distorted velocity distribution (see Eq. (3)) is utilized in Eq. (4). It is therefore, of interest to compare the momentum transfer collision frequency calculated using both definitions of Eq. (3) and (4). In addition, one can also define ν_m in the usual manner for a given velocity distribution with no external force imposed on the plasma electrons, that is;

$$\nu_a = B \int 4\pi v^3 \sigma(v) f(v) dv \tag{5}$$

where B is the normalization constant.

3. THE ELECTRON MOMENTUM TRANSFER COLLISION FREQUENCY IN N_2

We utilize the electron $-N_2$ momentum transfer cross section given in Ref. (3) to calculate the appropriate collision frequencies, ν_m, ν_{eff} and ν_a as defined by Eq. (3), (4) and (5), respectively. The results are given in Table 1 for an electron energy range of 0.1 to 50 eV.

The momentum transfer cross sections N_2 for electron energies higher than 20 eV show an apparent disagreement (see Ref. 3 for details), where several appropriate curves can be drawn beyond 20 eV. The results of Table 1, which are shown in Figs. 1a and 1b are based on the calculations of Shyn, et al[4]. However, this cross section is slightly lower than the most recent measurements of Shyn and Carignan[5]. However, this does not affect the results presented here.

In Fig. 2 we compare our results for ν_m, ν_{eff} and ν_a with the calculations of Itikawa[6] for ν_m and ν_{eff} for a Maxwellian electron velocity distribution. The agreement is excellent. We further compare our results with the Swarm data obtained by Englehardt, et al[7]. The disagreement between the Swarm result and the calculations could be as high as 100% in some regions. This discrepancy is clearly due to the fact that the electron distribution in a Swarm experiment is not Maxwellian. On the other hand the calculated results of ν_{eff} and ν_a seem to get closer to the Swarm data for $T_e < 1.0$ eV where electron molecule collisions are dominated by elastic collisions rendering the distribution Maxwellian.

4. THE ELECTRON MOMENTUM TRANSFER CROSS SECTION IN O_2

The momentum transfer cross section for O_2 is in a better shape, at high energies, compared to that for N_2 (see Ref. 3). The data by Shyn and Sharp[8] are in reasonable agreement with the data obtained by Ali[3] from the total

elastic cross section of Wedde and Strand[9]. Using these data we calculate ν_m, ν_{eff} and ν_a and the results are given in Table 2.

5. THE ELECTRON MOMENTUM TRANSFER COLLISION FREQUENCY IN AIR

To obtain the collision frequency in air we emphasize the calculation of ν_m (see Eq. 3) where in the averaging process the cross section is the denominator. Table 3 shows the results for ν_m with $\sigma_{air} = 0.8\,\sigma_{N_2} + 0.2\,\sigma_{O_2}$. Furthermore, we use the results of Table 1 for ν_m in N_2 and O_2 and combine them as $0.8\,\nu_m(N_2) + 0.2\,\nu_m(O_2)$. These results are also shown in Table 3. An interesting result, at least in this case where the distribution is Maxwellian, is that the results, obtained both ways, are in excellent agreement.

Table 1 — ν_m/N, ν_{eff}/N and ν_a/N for N_2

T_e	ν_m/N_2	ν_{eff}/N_2	ν_a/N_2
0.1	1.61E-08	2.33E-08	1.51E-08
0.2	2.82E-08	3.72E-08	2.53E-08
0.3	3.79E-08	5.24E-08	3.41E-08
0.4	4.71E-08	7.22E-08	4.40E-08
0.5	5.66E-08	9.32E-08	5.50E-08
0.6	6.61E-08	1.12E-07	6.64E-08
0.7	7.54E-08	1.27E-07	7.74E-08
0.8	8.44E-08	1.38E-07	8.75E-08
0.9	9.26E-08	1.47E-07	9.65E-08
1.0	1.00E-07	1.53E-07	1.04E-07
1.1	1.07E-07	1.57E-07	1.11E-07
1.2	1.13E-07	1.60E-07	1.17E-07
1.3	1.18E-07	1.62E-07	1.22E-07
1.4	1.22E-07	1.64E-07	1.26E-07
1.5	1.26E-07	1.65E-07	1.30E-07
1.6	1.30E-07	1.65E-07	1.33E-07
1.7	1.33E-07	1.66E-07	1.36E-07
1.8	1.36E-07	1.66E-07	1.38E-07
1.9	1.38E-07	1.66E-07	1.41E-07
2.0	1.40E-07	1.67E-07	1.42E-07
2.1	1.42E-07	1.67E=07	1.44E-07
2.2	1.44E-07	1.67E-07	1.46E-07
2.3	1.46E-07	1.67E-07	1.47E-07
2.4	1.47E-07	1.67E-07	1.48E-07
2.5	1.49E-07	1.67E-07	1.49E-07

Table 1 (Cont'd) — ν_m/N, ν_{eff}/N and ν_a/N for N_2

T_e	ν_m/N_2	ν_{eff}/N_2	ν_a/N_2
2.6	1.50E-07	1.68E-07	1.50E-07
2.7	1.51E-07	1.68E-07	1.51E-07
2.8	1.52E-07	1.68E-07	1.52E-07
2.9	1.53E-07	1.68E-07	1.53E-07
3.0	1.54E-07	1.68E-07	1.54E-07
3.1	1.55E-07	1.68E-07	1.54E-07
3.2	1.56E-07	1.69E-07	1.55E-07
3.3	1.57E-07	1.69E-07	1.56E-07
3.4	1.57E-07	1.69E-07	1.56E-07
3.5	1.58E-07	1.69E-07	1.57E-07
3.6	1.59E-07	1.70E-07	1.57E-07
3.7	1.60E-07	1.70E-07	1.58E-07
3.8	1.60E-07	1.70E-07	1.58E-07
3.9	1.61E-07	1.70E-07	1.59E-87
4.0	1.61E-07	1.70E-07	1.59E-07
4.1	1.62E-07	1.70E-07	1.60E-07
4.2	1.62E-07	1.71E-07	1.60E-07
4.3	1.62E-07	1.71E-07	1.60E-07
4.4	1.63E-07	1.71E-07	1.61E-07
4.5	1.63E-07	1.71E-07	1.61E-07
4.6	1.64E-07	1.71E-07	1.61E-07
4.7	1.64E-07	1.71E-07	1.61E-07
4.8	1.64E-07	1.71E-07	1.62E-07
4.9	1.64E-07	1.71E-07	1.62E-07
5.0	1.64E-07	1.71E-07	1.62E-07

Table 1 (Cont'd) — ν_m/N, ν_{eff}/N and ν_a/N for N_2

T_e	ν_m/N_2	ν_{eff}/N_2	ν_a/N_2
6.0	1.65E-07	1.71E-07	1.64E-07
7.0	1.63E-07	1.69E-07	1.65E-07
8.0	1.61E-07	1.66E-07	1.66E-07
9.0	1.58E-07	1.63E-07	1.66E-07
10.0	1.55E-07	1.60E-07	1.65E-07
11.0	1.51E-07	1.57E-07	1.64E-07
12.0	1.48E-07	1.54E-07	1.63E-07
13.0	1.44E-07	1.51E-07	1.62E-07
14.0	1.41E-07	1.48E-07	1.60E-07
15.0	1.38E-07	1.45E-07	1.59E-07
16.0	1.35E-07	1.43E-07	1.58E-07
17.0	1.32E-07	1.40E-07	1.56E-07
18.0	1.30E-07	1.37E-07	1.55E-07
19.0	1.27E-07	1.35E-07	1.53E-07
20.0	1.25E-07	1.33E-07	1.52E-07
21.0	1.22E-07	1.31E-07	1.50E-07
22.0	1.20E-07	1.29E-07	1.49E-07
23.0	1.18E-07	1.27E-07	1.48E-07
24.0	1.16E-07	1.25E-07	1.46E-07
25.0	1.14E-07	1.23E-07	1.45E-07
26.0	1.12E-07	1.21E-07	1.44E-07
27.0	1.10E-07	1.19E-07	1.42E-07
28.0	1.08E-07	1.18E-07	1.41E-07
29.0	1.06E-07	1.16E-07	1.40E-07
30.0	1.04E-07	1.14E-07	1.39E-07

Table 1 (Cont'd) — ν_m/N, ν_{eff}/N and ν_a/N for N_2

T_e	ν_m/N_2	ν_{eff}/N_2	ν_a/N_2
31.0	1.03E-07	1.13E-07	1.37E-07
32.0	1.01E-07	1.11E-07	1.36E-07
33.0	9.98E-08	1.10E-07	1.35E-07
34.0	9.84E-08	1.11E-07	1.34E-07
35.0	9.69E-08	1.07E-07	1.33E-07
36.0	9.56E-08	1.06E-07	1.32E-07
37.0	9.43E-08	1.05E-07	1.29E-07
38.0	9.32E-08	1.03E-07	1.30E-07
39.0	9.19E-08	1.02E-07	1.29E-07
40.0	9.08E-07	1.01E-07	1.28E-07
41.0	8.95E-08	9.99E-07	1.26E-07
42.0	8.86E-08	9.88E.08	1.26E-07
43.0	8.75E-08	9.77E.08	1.25E-07
44.0	8.65E-08	9.67E-08	1.24E-87
45.0	8.51E-08	9.57E-08	1.23E-07
46.0	8.45E-08	9.47E-08	1.22E-07
47.0	8.35E-08	9.38E-08	1.21E-87
48.0	8.28E-08	9.32E-08	1.20E-07
49.0	8.18E-08	9.20E-08	1.19E-07
50.0	8.10E-08	9.11E-08	1.18E-07

Table 2 — ν_m/O_2, ν_{eff}/O_2 and ν_a/O_2 for O_2

t_e	ν_m/O_2	ν_{eff}/O_2	ν_a/O_2
0.1	5.93E-09	1.10E-08	6.84E-09
0.2	1.26E-08	2.10E-08	1.30E-08
0.3	1.89E-08	2.88E-08	1.86E-08
0.4	2.45E-08	3.53E-08	2.33E-08
0.5	2.96E-08	4.10E-08	2.76E-08
0.6	3.42E-08	4.89E-08	3.14E-08
0.7	3.86E-08	5.16E-08	3.51E-08
0.8	4.27E-08	5.66E-08	3.85E-08
0.9	4.66E-08	6.14E-08	4.18E-08
1.0	5.04E-08	6.59E-08	4.50E-08
1.1	5.40E-08	7.02E-08	4.81E-08
1.2	5.75E-08	7.44E-08	5.10E-08
1.3	6.08E-08	7.83E-08	5.39E-08
1.4	6.14E-08	8.20E-08	5.66E-08
1.5	6.73E-08	8.56E-08	5.93E-08
1.6	7.03E-08	8.90E-08	6.19E-08
1.7	7.33E-08	9.23E-08	6.44E-08
1.8	7.61E-08	9.55E-08	6.68E-08
1.9	7.89E-08	9.85E-08	7.03E-08
2.0	8.17E-08	1.01E-07	7.14E-08
2.1	8.43E-08	1.04E-07	7.36E-08
2.2	8.68E-08	1.07E-07	7.58E-08
2.3	8.93E-08	1.09E-07	7.78E-08
2.4	9.17E-08	1.12E-07	7.98E-08
2.5	9.40E-08	1.14E-07	8.18E-08

Table 2 (Cont'd) — ν_m/O_2, ν_{eff}/O_2 and ν_a/O_2 for O_2

T_e	ν_m/O_2	ν_{eff}/O_2	ν_a/O_2
2.6	9.63E-08	1.16E-07	8.37E-08
2.7	9.84E-08	1.18E-07	8.55E-08
2.8	1.01E-07	1.20E-07	8.73E-08
2.9	1.03E-07	1.22E-07	8.90E-08
3.0	1.04E-07	1.24E-07	9.07E-08
3.1	1.06E-07	1.26E-07	9.23E-08
3.2	1.08E-07	1.27E-07	9.39E-08
3.3	1.10E-07	1.29E-07	9.54E-08
3.4	1.12E-07	1.30E-07	9.69E-08
3.5	1.13E-07	1.32E-07	9.84E-08
3.6	1.15E-07	1.33E-07	9.98E-08
3.7	1.17E-07	1.34E-07	1.01E-07
3.8	1.18E-07	1.35E-07	1.02E-07
3.9	1.19E-07	1.36E-07	1.04E-07
4.0	1.21E-07	1.37E-07	1.05E-07
4.1	1.22E-07	1.38E-07	1.06E-07
4.2	1.23E-07	1.39E-07	1.07E-07
4.3	1.25E-07	1.40E-07	1.08E-07
4.4	1.26E-07	1.41E-07	1.10E-07
4.5	1.27E-07	1.42E-07	1.11E-07
4.6	1.28E-07	1.43E-07	1.12E-07
4.7	1.29E-07	1.44E-07	1.13E-07
4.8	1.30E-07	1.44E-07	1.14E-07
4.9	1.31E-07	1.45E-07	1.15E-07
5.0	1.32E-07	1.46E-07	1.16E-07

Table 2 (Cont'd) — ν_m/O_2, ν_{eff}/O_2 and ν_a/O_2 for O_2

T_e	ν_m/O_2	ν_{eff}/O_2	ν_a/O_2
6.0	1.40E-07	1.51E-07	1.23E-07
7.0	1.45E-07	1.54E-07	1.29E-07
8.0	1.48E-07	1.55E-07	1.34E-07
9.0	1.50E-07	1.56E-07	1.37E-07
10.0	1.50E-07	1.56E-07	1.40E-07
11.0	1.50E-07	1.56E-07	1.42E-07
12.0	1.49E-07	1.55E-07	1.44E-07
13.0	1.47E-07	1.53E-07	1.45E-07
14.0	1.45E-07	1.52E-07	1.46E-07
15.0	1.42E-07	1.50E-07	1.46E-07
16.0	1.39E-07	1.48E-07	1.46E-07
17.0	1.36E-07	1.46E-07	1.46E-07
18.0	1.33E-07	1.44E-07	1.46E-07
19.0	1.29E-07	1.42E-07	1.46E-07
20.0	1.26E-07	1.40E-07	1.46E-07
21.0	1.22E-07	1.37E-07	1.45E-07
22.0	1.19E-07	1.35E-07	1.45E-07
23.0	1.16E-07	1.33E-07	1.44E-07
24.0	1.12E-07	1.31E-07	1.43E-07
25.0	1.09E-07	1.29E-07	1.42E-07
26.0	1.06E-07	1.27E-07	1.41E-07
27.0	1.03E-07	1.24E-07	1.41E-07
28.0	1.01E-07	1.22E-07	1.40E-07
29.0	9.81E-08	1.20E-07	1.39E-07
30.0	9.57E-08	1.18E-07	1.38E-07

Table 2 (Cont'd) — ν_m/O_2, ν_{eff}/O_2 and ν_a/O_2 for O_2

T_e	ν_m/O_2	ν_{eff}/O_2	ν_a/O_2
31.0	9.35E-08	1.16E-07	1.37E-07
32.0	9.13E-08	1.15E-07	1.36E-07
33.0	8.93E-08	1.13E-07	1.35E-07
34.0	8.71E-08	1.11E-07	1.34E-07
35.0	8.57E-08	1.10E-07	1.33E-07
36.0	8.38E-08	1.08E-07	1.32E-07
37.0	8.24E-08	1.06E-07	1.31E-07
38.0	8.08E-08	1.05E-07	1.30E-07
39.0	7.94E-08	1.03E-07	1.29E-07
40.0	7.81E-08	1.02E-07	1.28E-07
41.0	7.67E-08	1.00E-07	1.27E-07
42.0	7.56E-08	9.90E-07	1.26E-07
43.0	7.40E-08	9.74E-08	1.25E-07
44.0	7.33E-08	9.64E-08	1.24E-07
45.0	7.23E-08	9.49E-08	1.23E-07
46.0	7.13E-08	9.55E-08	1.22E-07
47.0	7.04E-08	9.25E-08	1.21E-07
48.0	6.95E-08	9.18E-08	1.20E-07
49.0	6.84E-08	9.06E-08	1.19E-07
50.0	6.78E-08	8.95E-08	1.18E-07

Table 3 — ν_m/N_o in air

T_e	ν_m/N_o	$0.8\ \nu_m/N_2 + 0.2\ \nu_m/O_2$
0.1	1.43E-08	1.41E-08
0.2	2.53E-08	2.51E-08
0.3	3.44E-08	3.41E-08
0.4	4.30E-08	4.26E-08
0.5	5.16E-08	5.12E-08
0.6	6.03E-08	5.97E-08
0.7	6.88E-08	6.81E-08
0.8	7.69E-08	7.60E-08
0.9	8.44E-08	8.34E-08
1.0	9.14E-08	9.02E-08
1.1	9.76E-08	9.63E-08
1.2	1.03E-07	1.02E-07
1.3	1.08E-07	1.06E-07
1.4	1.12E-07	1.11E-07
1.5	1.16E-07	1.15E-07
1.6	1.20E-07	1.18E-07
1.7	1.23E-07	1.21E-07
1.8	1.26E-07	1.24E-07
1.9	1.28E-07	1.26E-07
2.0	1.31E-07	1.28E-07
2.1	1.33E-07	1.31E-07
2.2	1.35E-07	1.33E-07
2.3	1.37E-07	1.34E-07
2.4	1.38E-07	1.36E-07
2.5	1.40E-07	1.38E-07

Table 3 (Cont'd) — ν_m/N_o in air

T_e	ν_m/N_o	$0.8\ \nu_m/N_2 + 0.2\ \nu_m/O_2$
2.6	1.41E-07	1.39E-07
2.7	1.43E-07	1.40E-07
2.8	1.44E-07	1.42E-07
2.9	1.45E-07	1.43E-07
3.0	1.47E-07	1.44E-07
3.1	1.48E-07	1.45E-07
3.2	1.49E-07	1.46E-07
3.3	1.50E-07	1.47E-07
3.4	1.51E-07	1.48E-07
3.5	1.52E-07	1.49E-07
3.6	1.52E-07	1.50E-07
3.7	1.53E-07	1.51E-07
3.8	1.54E-07	1.52E-07
3.9	1.54E-07	1.52E-07
4.0	1.55E-07	1.53E-07
4.1	1.56E-07	1.54E-07
4.2	1.56E-07	1.54E-07
4.3	1.57E-07	1.55E-07
4.4	1.57E-07	1.55E-07
4.5	1.58E-07	1.56E-07
4.6	1.58E-07	1.56E-07
4.7	1.59E-07	1.57E-07
4.8	1.59E-07	1.57E-07
4.9	1.59E-07	1.58E-07
5.0	1.60E-07	1.58E-07

Table 3 (Cont'd) — ν_m/N_o in air

T_e	ν_m/N_o	$0.8\ \nu_m/N_2 + 0.2\ \nu_m/O_2$
6.0	1.61E-07	1.60E-07
7.0	1.61E-07	1.59E-07
8.0	1.60E-07	1.58E-07
9.0	1.58E-07	1.56E-07
10.0	1.55E-07	1.54E-07
11.0	1.52E-07	1.51E-07
12.0	1.49E-07	1.48E-07
13.0	1.46E-07	1.45E-07
14.0	1.43E-07	1.42E-07
15.0	1.40E-07	1.39E-07
16.0	1.37E-07	1.36E-07
17.0	1.34E-07	1.33E-07
18.0	1.31E-07	1.30E-07
19.0	1.29E-07	1.28E-07
20.0	1.26E-07	1.25E-07
21.0	1.23E-07	1.22E-07
22.0	1.21E-07	1.20E-07
23.0	1.19E-07	1.17E-07
24.0	1.16E-07	1.15E-07
25.0	1.14E-07	1.13E-07
26.0	1.12E-07	1.10E-07
27.0	1.10E-07	1.08E-07
28.0	1.07E-07	1.06E-07
29.0	1.06E-07	1.04E-07
30.0	1.04E-07	1.03E-07

Table 3 (Cont'd) — ν_m/N_o in air

T_e	ν_m/N_0	$0.8\ \nu_m/N_2 + 0.2\ \nu_m/O_2$
31.0	1.03E-07	1.01E-07
32.0	1.01E-07	9.94E-08
33.0	9.92E-08	9.77E-08
34.0	9.77E-08	9.61E-08
35.0	9.62E-08	9.47E-08
36.0	9.48E-08	9.33E-08
37.0	9.34E-08	9.19E-08
38.0	9.21E-08	9.07E-08
39.0	9.08E-08	8.94E-08
40.0	8.96E-08	8.82E-08
41.0	8.85E-08	8.70E-08
42.0	8.69E-08	8.60E-08
43.0	8.57E-08	8.48E-08
44.0	8.52E-08	8.38E-08
45.0	8.42E-08	8.25E-08
46.0	8.32E-08	8.19E-08
47.0	8.23E-08	8.09E-08
48.0	8.14E-08	8.01E-08
49.0	7.79E-08	7.91E-08
50.0	7.83E-07	7.83E-08

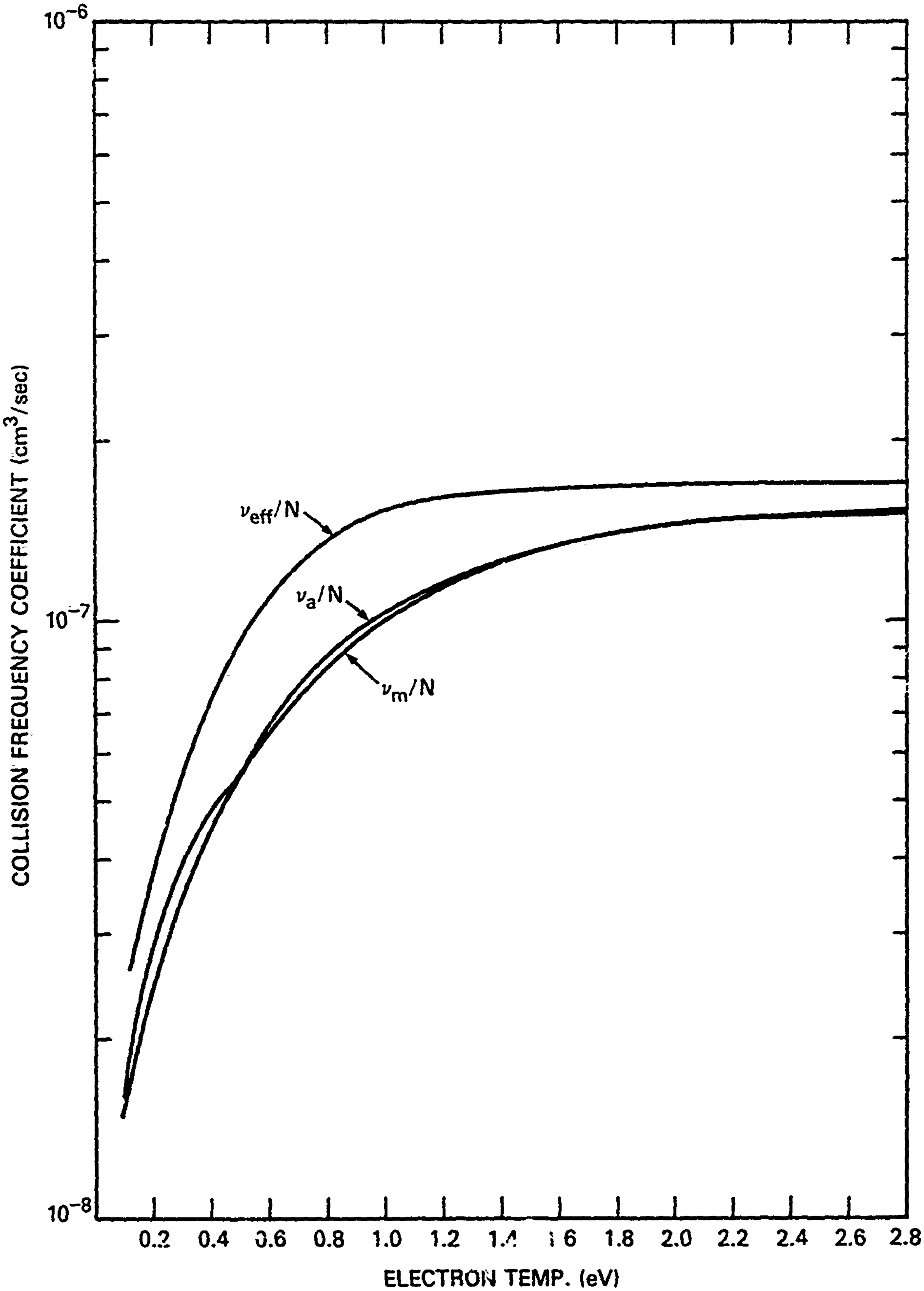

Figure 1a Collision frequency coefficients for momentum transfer in N_2.

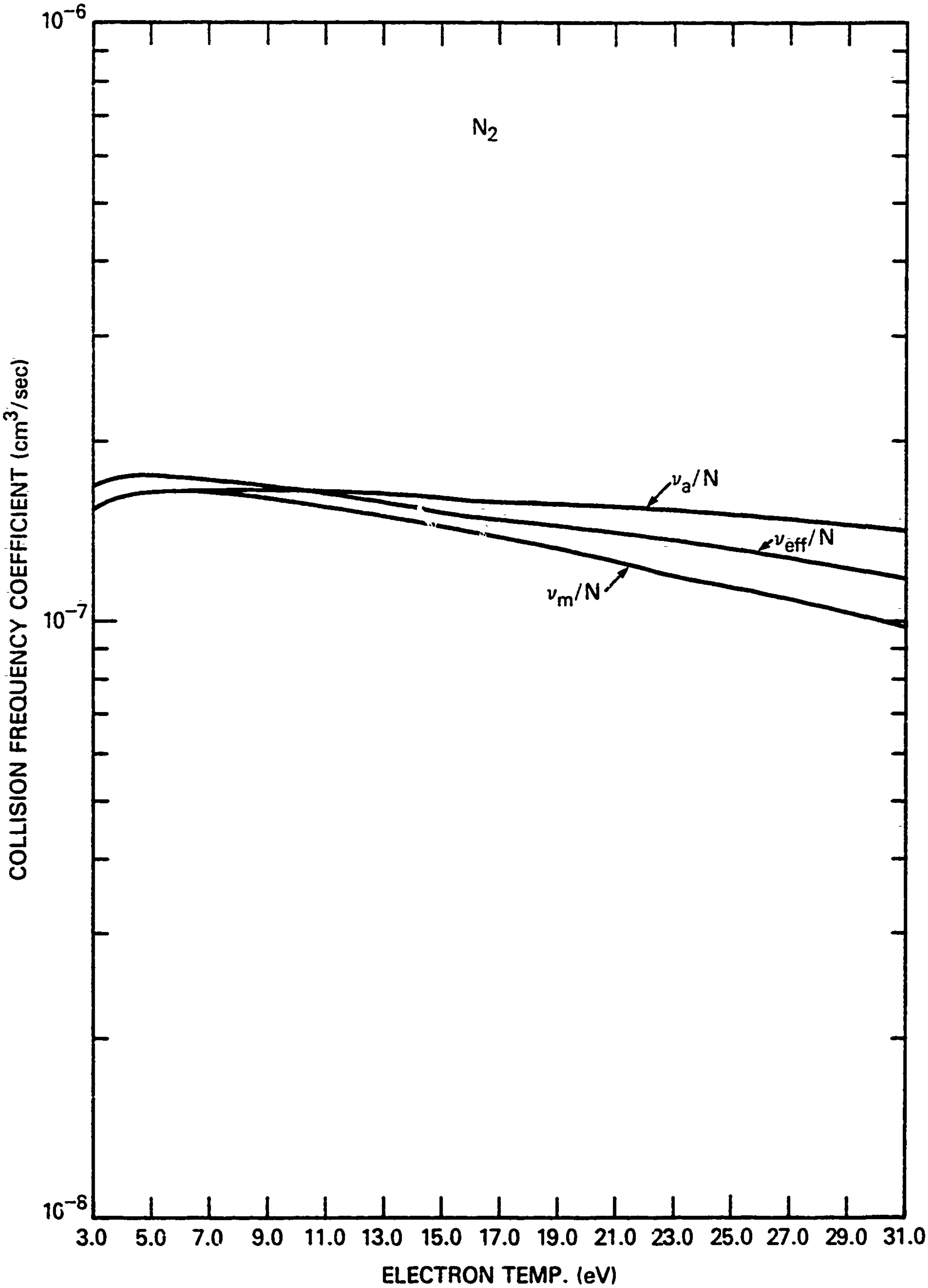

Figure 1b Collision frequency coefficients for momentum transfer in N_2.

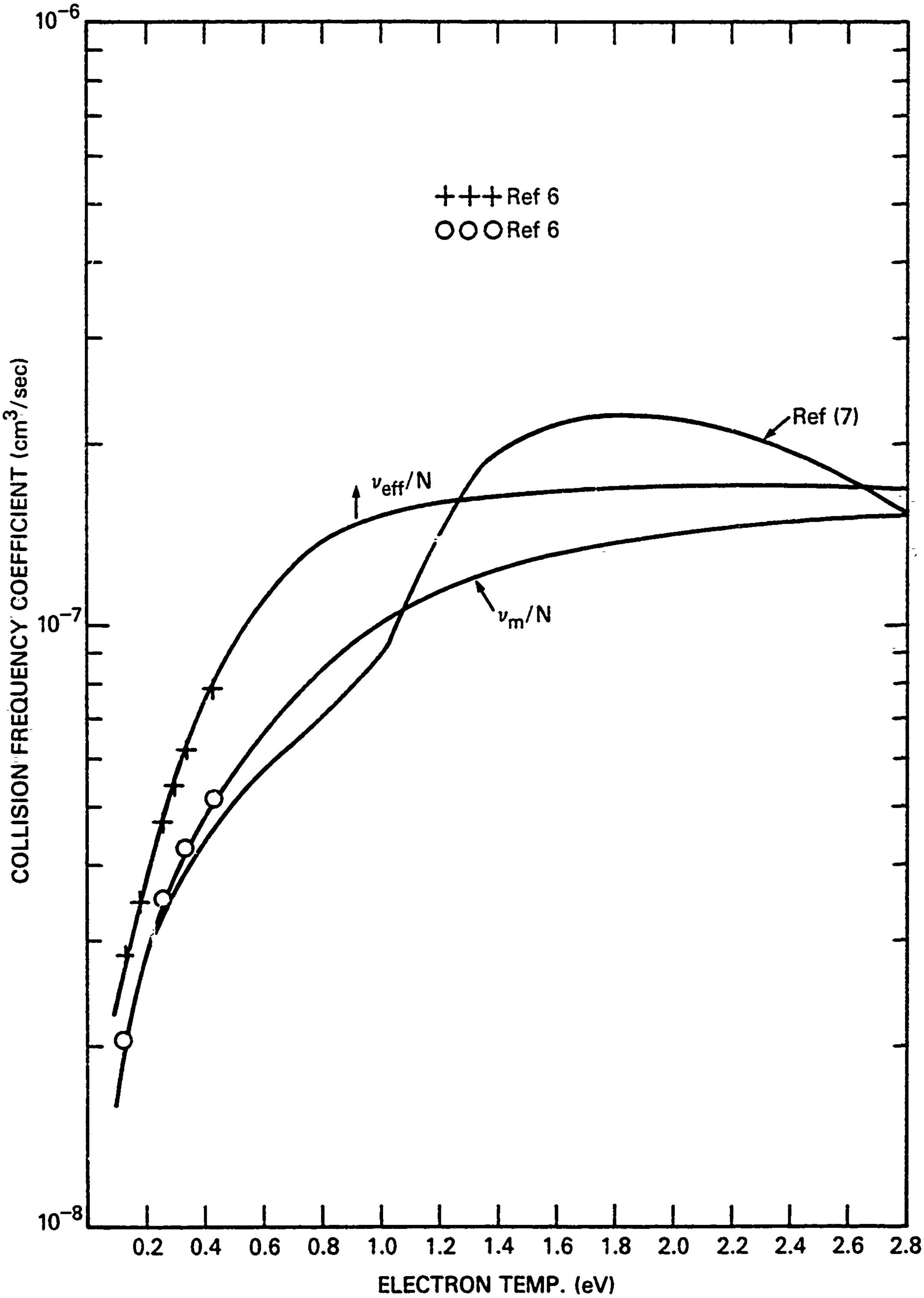

Figure 2 Collision frequency coefficients for momentum transfer in N_2.

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